UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

HYDRAULIC AND BITUMINOUS STUDIES OF AINSWORTH CANAL DUNE SAND MISSOURI RIVER BASIN PROJECT, NEBRASKA

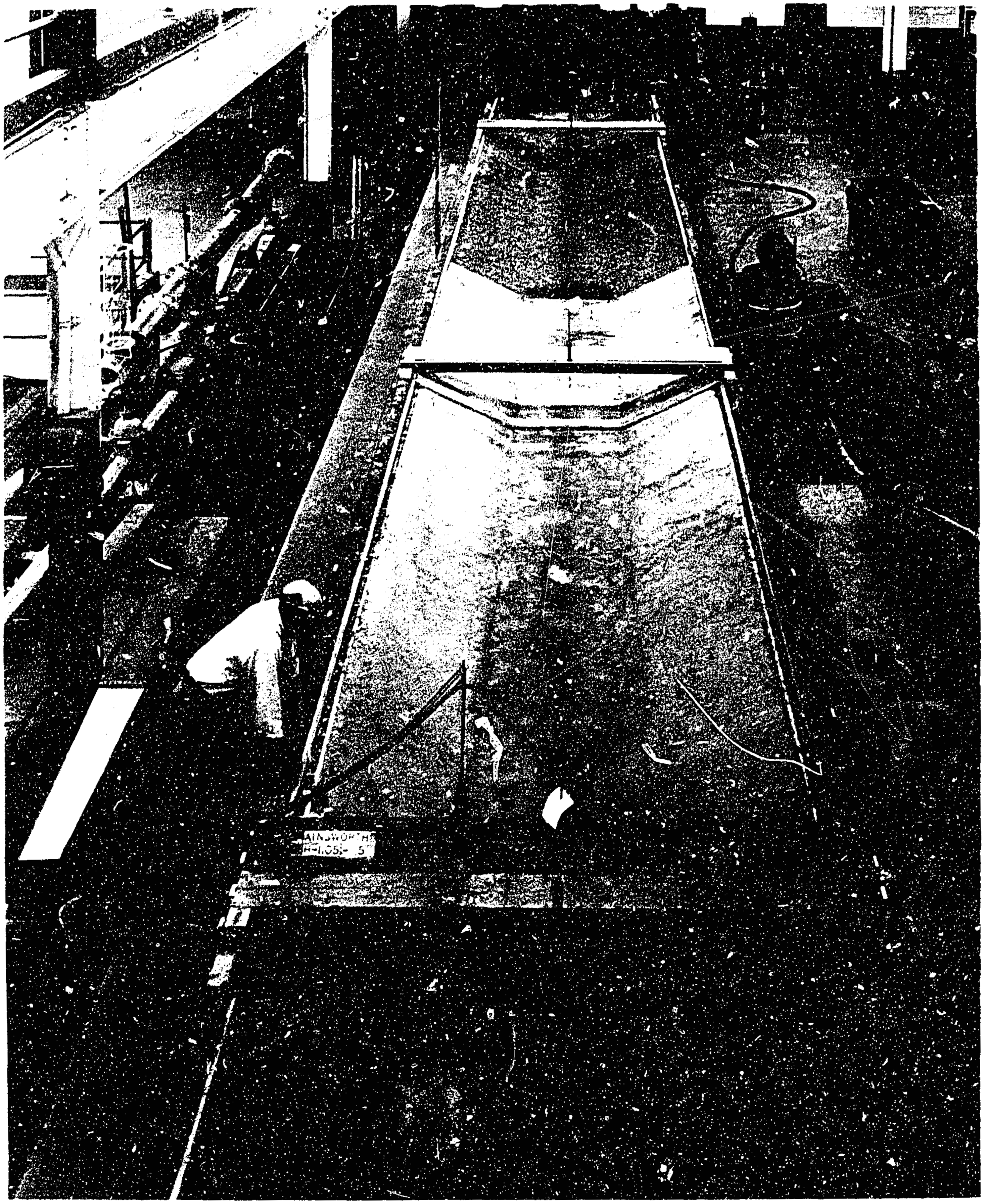
General Report No. 18

SAME AS HYD. 393

ENGINEERING LABORATORIES

OFFICE OF THE ASSISTANT COMMISSIONER AND CHIEF ENGINEER
DENVER, COLORADO

November 15, 1954



Missouri River Basin Project
AINSWORTH CANAL
HYDRAULIC TEST FLUME WITH DUNE SAND PLACED
hydraulic and bituminous studies
frontispiece

FOREWORD

Hydraulic and bituminous studies using dune sand from the Ainsworth Canal site, Missouri River Basin Project, Nebraska, were conducted in the Engineering Laboratories of the Bureau of Reclamation at Denver, Colorado, during 1953 and 1954.

During the studies, the model was frequently observed by personnel from Region 7, Niobrara River Area office, and the Canals Branch of the Bureau of Reclamation. Meetings were arranged to discuss test results, and the keen interest of the observers resulted in many helpful suggestions.

The studies were conducted by J. W. Short, R. A. Dodge, A. L. Smith, A. A. Kern and P. "F." Enger under the supervision of E. J. Carlson and L. M. Ellsperman.

CONTENTS

CONTENTS--Continued

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Office of the Assistant Commissioner and Chief Engineer
Engineering Laboratories
Denver, Colorado
November 15, 1954

*General Report No. 18
Bituminous Laboratory and Hydraulic Laboratory
Compiled and checked by: P. "F." Enger, L. M. Ellsperman
Reviewed by: E. J. Carlson

Subject: Hydraulic and bituminous studies of Ainsworth Canal dune sand--Missouri River Basin Project, Nebraska

SUMMARY

Tests were conducted on dune sand, shipped from the site of the Ainsworth Canal, Missouri River Basin Project, Nebraska, primarily to determine allowable tractive forces. Hydraulic tests, Figure 9, showed the untreated, unlined dune sand began to move at an average tractive force of approximately 0.004 pound per square foot and was undergoing movement over the entire wetted perimeter at an average tractive force of approximately 0.011 pound per square foot.

In determining the tractive force that would move the dune sand, the distribution of tractive forces around the wetted perimeter was studied. An example of a measured tractive force distribution around the wetted perimeter of a channel, of the shape shown, may be seen in Figure 10. Movement of the sand first appeared to start near the bottom of the side slopes, as shown in Figure 8.

Tests to determine the effects of a high ground-water table and rapid draw-down indicated a slope of 4:1 was necessary for stability against sloughing of the untreated or unlined dune sand. Examples of sloughing which may occur on a 2:1 side slope are shown in Figures 11 and 12.

Tests on bituminous stabilized dune sand and penetrated macadam cover** were conducted. The tests showed that the dune sand penetrated with diluted asphalt emulsion was erosion-resistant under maximum tractive forces resulting from the tests, but became soft and lost cohesion under freezing and thawing action. After thawing

*See Laboratory Reports No. Hyd-393 and B-21.

**Gravel, smaller than 3/8 inch, was penetrated by approximately 2.5 gallons per square yard of a rapid-setting emulsion.

and redrying, the treated dune sand regained most of its original stability. The penetrated macadam cover withstood high tractive forces and remained stable through the freezing and thawing tests.

INTRODUCTION

As shown in Figure 1, Ainsworth Canal is to be located in the Niobrara River Basin in Nebraska and is part of the Missouri River Basin Project. Starting at the Merritt Reservoir, it runs east across wind deposited sand hills for approximately 50 miles and, as given in the recent Definite Plan Report, will carry approximately 620 cfs of irrigation water to the Ainsworth Unit.

A preliminary canal design at the time the tests were made of a typical unlined section based on approximately 980 cfs as shown in Figure 2, was 8 feet deep with a 40-foot bottom width, and 2 or 2-1/2:1 side slopes. The maximum tractive forces which would occur in a straight section of the preliminary design as computed from the formula $T_0 = wds$ were found to range from 0.035 to 0.045 pounds per square foot.

To determine the limiting tractive force of the dune sand, tests were conducted in the Hydraulic Laboratory. Dune sand was shipped from the site to the Denver laboratories for these tests. The sand was placed in a test flume at field density, and the tractive forces acting on it were increased by increments. Data were taken to determine the tractive forces at which the sand began to move.

Tests involving a ground-water table higher than the invert of the canal, and rapid draw-down, were conducted. Over part of the proposed 50-mile length of canal, the ground-water table is expected to be higher than the bottom of the canal; therefore, provisions were made to introduce ground water into the sand, and effects of a high ground-water table on the empty canal were investigated.

Tests were made using dilute asphalt emulsion as a surface treatment to stabilize the dune sand. Preliminary penetration tests were performed to obtain the most satisfactory dilutions and quantities of asphaltic materials which would provide adequate penetration into the dune sand and also provide resistance to moderate tractive forces. The most satisfactory dilutions and quantities were sprayed on the dune sand and, after curing, its resistance to tractive forces was investigated. A penetrated macadam cover (fine gravel penetrated with asphalt emulsion) was also investigated.

To further evaluate the two types of bituminous construction, their resistance to alternate cycles of freezing and thawing were determined.

The freeze-thaw tests were conducted under simulated field conditions by maintaining a ground-water table higher than the invert of the canal which represents the most severe condition expected.

CONSTRUCTION AND OPERATION OF EQUIPMENT

As shown in Figure 3 and in the frontispiece, the arrangement for the hydraulic tests of the Ainsworth dune sand consisted of a head box, a baffle for stilling the water, a flume 70 feet long by 8 feet wide by 22-1/2 inches deep, a tail box, and a control gate. The flume, head box, and tail box were available in the Hydraulic Laboratory and were utilized for the study. The actual tractive forces to which the dune sand was subjected were measured. To obtain tractive forces comparable to those in the canal, the slope of the model was made steeper than the slope of the canal because of the smaller depths in the model. No model scale was used.

The flume, Figure 3, was prepared for the hydraulic tests as follows: From Station 0+00 to Station 0+40, 2:1 side slopes of wood covered with metal lath were placed in the flume. Over the wood and metal lath framework, gravel of 1/4 to 3/8 inch was placed so that the bottom width of the channel was 2 feet 10 inches and the side slopes were 2:1. From Station 0+30 to Station 0+40, the gravel was held in place by a water-cement mixture. Twenty feet of dune sand test section was constructed to the same contour between Station 0+40 and Station 0+60. From Station 0+60 to Station 0+70, the construction was the same as that between Station 0+00 and Station 0+30. A piping system from a water tank was connected to two 2-inch rock-filled water collectors along the sides of the test section, Figure 3. The water tank was adjustable, and by setting the tank at a given elevation and allowing a garden hose to discharge into the tank so that water just spilled over its edge, various ground-water conditions could be represented in the test section. The dune sand was compacted to the average field density of 102.5 pounds per cubic foot by personnel from the Earth Materials Laboratory.

Prior to operation, the model was backfilled slowly to the test depth. The discharge was gradually raised in the supply line, and the water surface in the flume was maintained by manipulation of the tail-gate.

The discharge was measured by a laboratory Venturi meter, and the water-surface elevations were determined by point gages. The elevation of the ground water was determined by calibrated tubes connected to the ground-water collectors. Point velocities were read by means of a pitot tube bank, a pitot cylinder bank, and a sloping manometer board, Figures 4 and 5.

Two types of equipment were used to apply the dilute asphalt emulsion when used in hydraulic tests: (1) Chausee, Standard Model T-200, 220-gallon asphalt distributor with power spray attachment, flexible metallic-hose and hand spray bar; (2) Hudson Sprayer Model 253, 1-1/2-gallon tank.

For freeze-thaw tests, two sheet-metal containers (Figure 6) measuring 1 foot wide, 5 feet long, and 1 foot deep were placed on four-wheeled wooden platform carts and securely braced. The trays were trapezoidal shaped, which provided for construction of a dune sand section 1 foot wide with 2:1 side slopes, so that when the test surfaces were in place the cross section would be similar to that of the proposed canal and the hydraulic test model. The emulsion was applied with the Hudson sprayer. After curing, 6 inches of water was maintained over the bottom of the test section for the freeze-thaw test.

THE INVESTIGATIONS

Hydraulic Model Tests--Untreated Dune Sand

Tests to determine limiting tractive forces. The dune sand, on which the tests were conducted, was fairly uniform. As shown in Figure 7, 99 percent passed a U. S. Standard No. 30 sieve and 5 percent passed a U. S. Standard No. 200 sieve (0.590 to 0.074 mm). There was no appreciable cementing material in the sand.

The first tests were conducted to obtain the average tractive force required to move the sand and the area where movement first started. To aid in visual observations, some of the sand was dyed with methyl violet using the method explained in Civil Engineering, November 1941, pages 668 and 669. As shown in Figure 8a, a strip of dyed sand, 3 inches wide and approximately 1/16 inch thick, was placed at Station 0+46 and Station 0+55. The strips were observed to aid in determining when the dune sand started to move and where movement started.

The average tractive force was computed from the formula:
$T_o = wRs$

where

T_o = the average tractive force (pounds per square foot)

w = the specific weight of water (62.4 pounds per cubic foot)

R = the average hydraulic radius

s = the slope of the hydraulic energy gradient

Water-surface elevations were recorded for each change in discharge, and the hydraulic gradient was computed.

To obtain the limiting tractive forces, the model was started to operate at a low tractive force, and the tractive force was gradually increased until general movement of the sand occurred. Holding a depth of 1.00 foot at Station 0+60, the discharge was slowly raised to 2.5 cfs. The resulting average tractive force, as computed from T_o = wRs, was too small to move the sand. Holding the depth of 1.00 foot at Station 0+60, the discharge was gradually increased. As shown in Figure 9, when the discharge reached 3.5 cfs, with a corresponding average tractive force of 0.0041 pound per square foot, the dune sand started to move. Movement first occurred near the bottom of the side slopes, Figure 8b. However, there was little movement at the average tractive force of 0.0041 pound per square foot. The discharge was increased by small increments, and at 5.5 cfs, with a resulting tractive force of 0.0114 pound per square foot, general movement occurred over the entire wetted perimeter, Figure 9.

Although Manning's "n" value changed throughout the tests, as the test section became rougher due to moving material forming in waves, the average "n" value for the dune sand test section was calculated as 0.0164.

Tests to determine the distribution of tractive forces. Tests were conducted to determine the distribution of tractive forces around the wetted perimeter. The tests were a continuation of general studies being conducted on tractive forces. The following method was used for calculations.

As shown by H. A. Einstein, in the Soil Conservation Service Technical Bulletin No. 1026, the Von Karman logarithmic velocity distribution law for open channels may be written in the following form:

$$\frac{V_y}{\sqrt{\frac{T_o}{\rho}}} = 5.75 \log\left(30.2 \frac{y}{\Delta}\right)$$

where

V_y = the average point velocity (feet per second) at a distance y from the bed

T_o = the shear at the boundary (tractive force) pounds per square foot

ρ = the density of the water in slugs per cubic foot

Δ = the apparent roughness of the surface and contains a corrective parameter

5.75 = a constant which includes Von Karman's k value (assumed constant and equal to 0.4)

If the preceding equation is used and the velocity (V_1) at one point (y_1) is subtracted from the velocity (V_2) of another point (y_2) which is at a higher elevation, we obtain:

$$V_2 - V_1 = 5.75 \sqrt{\frac{T_o}{\rho}} \left[\log \frac{30.2 y_2}{\Delta} - \log \frac{30.2 y_1}{\Delta} \right]$$

or:

$$V_2 - V_1 = 5.75 \sqrt{\frac{T_o}{\rho}} \log \frac{y_2}{y_1}$$

from which:

$$T_o = \rho \left[\frac{V_2 - V_1}{5.75 \log \frac{y_2}{y_1}} \right]^2$$

In the preceding equation, the distances from the boundary should be measured perpendicular to the boundary, and velocities close to the boundary should be used.

If a given distance from the boundary is set for y_1 and y_2, the equation will reduce to the following form:

$$T_o = C (V_2 - V_1)^2$$

where

$$C = \text{a constant} = \frac{\rho}{\left[5.75 \log \frac{y_2}{y_1} \right]^2}$$

The preceding method depends on accurate determination of the position of the boundary, and as the elevation of the boundary continually changed after the dune sand started to move, some difficulty was experienced in obtaining a satisfactory boundary position. By recording the position of the boundary before and after a run and the time at which point velocities were measured, the approximate position of the boundary at the time point velocities were recorded could be determined. As the dune sand moved in a wave formation, only the approximate position of the boundary was obtained from this method. An example of one group of analyzed, plotted data may be seen in Figure 10. The discharge for the test shown was 6.00 cfs. Figure 9 shows the average tractive force throughout the test section to be 0.0137 pound per square foot when the discharge was equal to 6.00 cfs. The point-velocity method, Figure 10, shows the average tractive force acting at Station 0+57.5, which was near the end of the test section, to be 0.0180 pound per square foot. The average tractive force calculated from the point-velocity method is 31 percent higher than that indicated by Figure 9. The difference could be due to the increase in roughness of the test section from Station 0+40 to Station 0+60. The increase in roughness would increase the hydraulic gradient and, thus, a larger tractive force would act at Station 0+60 than at Station 0+40. In all point-velocity data, for the untreated sand, which was analyzed, the average tractive force at Station 0+57.5 was higher than the average tractive force shown by Figure 9.

Ground-water tests. Although extensive tests on ground-water conditions were not conducted, a test was performed to determine the effect of a high ground-water table on an empty canal. As shown in Figure 11, sloughing of the side slopes occurred.

In the test performed, the ground water was held 0.78 foot above the average elevation of the channel bottom. After approximately 10 minutes, water appeared on the bottom of the channel, and after approximately 15 minutes, small failures from sloughing began to occur. The sloughing progressed rapidly for approximately 45 minutes. After about 1 hour, the sloughing slowed considerably, Figure 11. The side slopes which resulted from the sloughing were approximately 4:1.

Rapid draw-down tests. The test section was subjected to rapid draw-down. A discharge of 1.94 cfs was set in the channel, and an average depth of 0.98 foot was maintained over the test section. The model was operated for 6 hours to saturate the dune sand. After the dune sand was well saturated, the discharge was turned off and simultaneously the tailgate was dropped. As shown in Figure 12, the side slopes sloughed from approximately 2:1 to approximately 3.33:1.

Tests to Determine the Best Bituminous Application

Prime-membrane type asphaltic canal lining experiments in Region 1 on the Payette Division of the Boise Project, Roza Division of the Yakima Project, and the Pasco Laterals of the Columbia Basin Project have shown that a surface treatment will provide increased stability, provided a proper selection of bituminous materials is correctly applied to the exposed surface of a sandy soil under temperature conditions that will allow absorption and penetration of the bituminous materials without excessive run-down. A lower-cost canal lining report, published by Region 1 in January 1949, entitled "Experimental Asphaltic Prime-Membrane Canal Linings" presents valuable data regarding the construction and serviceability of this type of stabilization. The subgrade of the East Turbine Lateral is defined as a fine "blow sand" (Figure 7) which is considered comparable to the Ainsworth material; therefore, the techniques and materials used on the East Turbine Lateral should be applicable to the Ainsworth area.

Some surface-penetration experiments employing bituminous materials were performed with the thought of economically providing cohesion in a surface layer of the in-place dune sand. The results of these experiments and the estimated costs of this type of slope stabilization are herein reported.

The Ainsworth sand was placed in 3-inch-diameter plastic cylinders fitted with wooden bases at the field in-place density of 102.5 pounds per cubic foot. The time to obtain a "surface dry condition" (when the bituminous material had been absorbed into the sand) and the depth of penetration of each application was recorded. Photographs of the test cylinders may be seen in Figure 13.

Cylinder No. 1. A canal lining emulsion with the catalytically blown asphalt cement as the base was added to the damp surface of the soil at a rate of 1.0 gallon per square yard. The asphalt fraction separated from the water in the emulsion or "broke" in 7 minutes forming a surface membrane. The penetration did not exceed 1/16 inch. After curing in an oven at 140° F for 18 hours, no additional penetration was observed.

Cylinder No. 2. One-half gallon per square yard of HRM or mixing-grade emulsion was added to the damp sand as above. The asphalt emulsion broke in 16 minutes forming a membrane. The asphalt penetrated 3/16 inch into the sand. Oven curing for 18 hours increased the depth of penetration 1/8 inch.

Cylinder No. 3. Using a blend of 1 part of "cat" emulsion (Cylinder No. 1) to 1 part of water at a rate of 1.0 gallon per square yard, the material broke in 25 minutes forming a surface membrane. The maximum penetration observed was 3/16 inch.

Cylinder No. 4. Diesel fuel, at a quantity of 1 gallon per square yard, was absorbed rapidly by the dry sand (7 seconds to a surface dry condition). The penetration was 3/8 inch. One and one-half hours later, SC-1 was added at a quantity of 1.0 gallon per square yard. A surface dry condition was observed in 28 minutes at which time the SC-1 had penetrated 7/16 inch and the diesel fuel a total of 1-3/8 inches. The following day, RC-0 was added to the surface in two equal applications of 0.25 gallon per square yard. The cylinder was cured in the 140° F oven overnight and then placed under an infrared lamp for 20 minutes. A layer, rich in asphalt, with a relatively stable crust, was formed by the above treatment.

Cylinder No. 5. Same as Cylinder No. 4, except the SC-1 was warmed to 180° F and applied in two equal applications of 0.5 gallon per square yard. A surface dry condition was observed in 3.5 minutes. As shown in Figure 13, the asphalt penetrated approximately 2-1/2 inches. The same firm surface as noted on Cylinder No. 4 was observed on Cylinder No. 5.

Cylinder No. 6. A preprime of 0.5 gallon per square yard of diesel fuel was applied to the dry sand followed by two applications of 0.5 gallon per square yard each of a blend consisting of 50 percent diesel fuel and 50 percent SC-1. The RC-0 was added as in Cylinder No. 4. The materials were absorbed readily. The depth of penetraton was 1-1/2 inches, as shown in Figure 13.

Cylinder No. 7. To the dry surface, without a preprime, 0.5 gallon per square yard of the same blend as used in Cylinder No. 6 provided a penetration of approximately 5/16 inches. A second similar application failed to increase the penetration significantly leaving an asphalt rich crust on the surface.

Cylinder No. 8. Four equal applications of 0.5 gallon per square yard of a blend of 1 part HRM (mixing grade) emulsion to 4 parts of water were applied to the surface of the damp sand. The material was absorbed rapidly. The depth of penetration was not clearly defined. The emulsion produced a fairly firm surface over a stratified layer about 1-3/8 inches thick. The final application, applied the following day, consisted of 0.5 gallon per square yard of a blend of 1 part HRM to 2 parts of water. This material was not absorbed too readily since it required 18 minutes to become surface dry. Total penetration was 1-3/4 inches.

Cylinder No. 9. Same as Cylinder No. 8, except the sample was placed under the infrared lamp for 30 minutes prior to the final application. This treatment retarded the absorption. It required 40 minutes for the surface to become dry.

Cylinder No. 10. Using dry sand, eight applications of 0.5 gallon per square yard of a blend composed of 1 part HRM emulsion and 9 parts water were made in quick succession. The observed penetration was approximately 2-1/4 inches. Since the emulsion was very dilute, the deep penetration was accomplished rapidly (3 inches in 40 minutes). One-half gallon per square yard of a 1:2 blend was applied to the surface and the cylinder placed under the infrared lamp for curing. The sand was firm after the curing period.

The estimated cost of materials for the preceding applications are:

Diesel fuel, per gallon	8.33 cents
SC-1, per gallon.	5.0 cents
RC-0, per gallon.	6.25 cents

The preceding are quoted fob Casper, Wyoming, in tank transport lots (approximately 5,500 gallons).

Asphalt emulsion, per gallon:

fob Kansas City, Missouri . . .	10.0 cents
fob Laurel, Montana	8.33 cents
In transport lots	

It is estimated that for volumes in the order of 100,000 gallons, the cost of application would be about 6 cents per gallon.

Hydraulic Model Tests of Bituminous Treated Material

The hydraulic test section was reshaped with dune sand placed at the field in-place density, and a slow setting asphalt emulsion, conforming to Federal Specification SS-A-674b, Type SS-1, was mixed with water and sprayed on the dune sand. Some difficulties were encountered in controlling the discharge of emulsion and application pressures when using the hand spray bar and the asphalt distributor. As shown in Figure 14a, considerable sloughing of the dune sand occurred due to oversaturation. Figure 14b shows that the Hudson sprayer produced satisfactory results.

The spraying operation was continuous. The following table shows the dilution and rate of application:

Application	Dilution		Quantity applied gallons	Application--gallons per square yard
	Parts water	Parts emulsion		
Prime	100	0	2.5	0.14
Penetration	8	1	85.0	4.88
Surface	1.75	1	10.8	0.62

A total of 13.3 gallons of asphalt emulsion was used in the stabilization treatment of 17.4 square yards of dune sand surface at 0.764 gallon per square yard. After first applying a water prime, approximately 70 percent of the asphalt emulsion was applied in the 8:1 dilution to obtain maximum penetration into the sand. The final surface treatment consisted of a 1.75:1 dilution.

Curing was accomplished by using a battery of infrared lamps. As shown in Figure 15a, some circular areas about 6 inches in diameter in which the cohesion of the asphalt was destroyed resulted from localized overheating. The burned areas would not occur in a properly sun-cured section in the field. With the exception of the burned areas, the section satisfactorily withstood over 200 hours of operation with the average tractive force varying from 0.015 to 0.055 pound per square foot. Except for the burned areas, the section appeared as though it would withstand higher tractive forces than those resulting from the tests.

A short section of penetrated macadam was constructed by applying approximately 2.5 gallons per square yard of a rapid-setting emulsion to the surface of the 1/4- to 3/8-inch gravel in the approach to the hydraulic test section of dune sand, Figure 3. Figure 15b shows the penetrated macadam and a battery of infrared lamps used in the curing process. The emulsion used for the penetrated macadam conformed with Federal Specification SS-A-674b, Type RS-1. To prevent excessive run-off on the side slopes, the emulsion was applied in two applications. The first application of approximately 1.5 gallons per square yard was followed by a second application of 1.0 gallon per square yard.

The penetrated macadam cover was unaffacted after over 200 hours' operation with average tractive forces varying from 0.015 to 0.055 pound per square foot, and it appeared as though it would withstand much higher tractive forces.

Freeze-thaw Tests

To further evaluate the penetrated dune sand and penetrated macadam cover, their resistance to alternate cycles of freezing and thawing was investigated. The freeze-thaw tests were conducted under simulated field conditions with a high water table by maintaining 6 inches of water over the bottom of the test section during the freeze-thaw test period.

In order to correlate the hydraulic tests with the accelerated freezing and thawing tests, the test specimens, in the two metal containers (Figure 6), were prepared as nearly identical with the sections in the model as possible. A slightly finer gravel was used for the penetrated macadam cover in freeze-thaw tests than was used in the hydraulic tests. However, there was no significant difference in the penetration characteristics of this finer material as compared with the test section constructed in the hydraulic model.

The following types of asphalt emulsion stabilization linings were prepared and tested:

a. Dune sand at the undisturbed field density penetrated with diluted asphalt emulsion (Tray 1, Section A, and Tray 2, Section D).

b. Same as a., above, with a penetrated macadam cover (Tray 1, Section B).

c. Dune sand at the undisturbed field density (untreated) with a penetrated macadam cover (Tray 2, Section C).

Figure 16 shows these test sections prior to testing.

The entire surface of Tray 1 and Section D of Tray 2 were prepared by penetrating the dune sand with asphalt emulsion (Federal Specification SS-A-674b, Type SS-1) at 0.764 gallon per square yard. Approximately 70 percent of the emulsion was diluted with 8 parts of water (8:1 mix) and applied to the exposed sand surface as a spray using the tank-type Hudson sprayer. The remaining 30 percent emulsion was then applied by the same method after diluting by adding 1.75 parts of water to 1 part of asphalt emulsion.

The penetrated macadam cover (Tray 1, Section B, and Tray 2, Section C) consisted of a 2-inch layer of fine gravel treated with standard rapid-setting asphalt emulsion (Federal Specification SS-A-674b, Type RS-1) at 2.5 gallons per square yard. The gravel was composed of 50 percent of 3/8-inch to No. 4 mesh material, mixed with 50 percent coarse sand passing the No. 4 sieve and retained on the No. 8 sieve. The emulsion was applied with the Hudson sprayer. Approximately 1.5 gallons per square yard was sprayed over the surface of the gravel. The asphalt emulsion rapidly penetrated into the voids of the gravel layer. A second application of 1.0 gallon per square yard was applied immediately. Some run-off of asphalt material was noted at the toe of the slope.

The test sections were wheeled into the freezing room and held at approximately minus 10° F overnight. Examination showed the entire mass to be completely frozen after the 16-hour freezing period. The test sections were allowed to thaw at room temperature before repeating the freezing process.

Thirty cycles of freezing and thawing were completed under this test program.

Figure 17 shows the test sections while frozen, and Figure 18 shows the condition of the test sections after removing the water at the completion of the test.

After 30 cycles of freezing and thawing, the following results were observed:

> Tray 1, Section A.--Above the water line the asphalt emulsion-stabilized dune sand remained relatively firm, but several irregular cracks from 1/8 to 1/4 inch wide developed. Below the water line, uncoated sand particles were noted with an accompanying loss in stability as evidenced by a slight sloughing on the side slope which produced a bulge at the toe of the slope. On thawing and redrying, the dune sand appeared to regain some of its original stability.
>
> Tray 1, Section B.--There was no apparent effect on the stability of the asphalt emulsion-penetrated macadam cover due to the freeze-thaw test. Any movement or sloughing in the underlying stabilized dune sand was not transferred to the macadam cover.
>
> Tray 2, Section D.--Same as Tray 1, Section A.
>
> Tray 2, Section C.--Unaffected. Resistant to 30 cycles of freezing and thawing.

RESULTS AND CONCLUSIONS

As shown in Figure 9, the untreated dune sand placed at field density started to move at an average tractive force of approximately

0.0041 pound per square foot and was, in general movement, over the entire wetted perimeter, at an average tractive force of approximately 0.0114 pound per square foot. The tractive forces at which the dune sand moved indicated that an unprotected or untreated dune sand canal would lose its shape when an average tractive force of approximately 0.0041 pound per square foot was maintained.

The point-velocity method of determining the tractive-force distribution at the wetted perimeter of an open channel appears feasible. Caution must be exercised in determining the position of the boundary, and velocities measured near the boundary should be used. The method gives better results with a fixed boundary than with a varying boundary.

A ground-water table above the invert of an unlined, untreated Ainsworth dune sand canal would cause sloughing of 2:1 side slopes if the canal were empty. To prevent sloughing from a high ground water table a 4:1 side slope would be required. A 4:1 side slope would also be adequate in preventing sloughing from rapid draw-down in an unlined, untreated Ainsworth dune sand canal.

The asphalt-emulsion stabilized dune sand withstood tractive forces up to 0.055 pound per square foot and appeared as though it would withstand much higher tractive forces, but became soft and lost its cohesion during freezing and thawing action. The test results indicate that the following minimum quantities should provide adequate stability for the high tractive force.

a.(1) 0.5 gallon per square yard diesel fuel

(2) 1.5-2.0 gallons per square yard of blended diesel fuel and SC-1 or MC-1

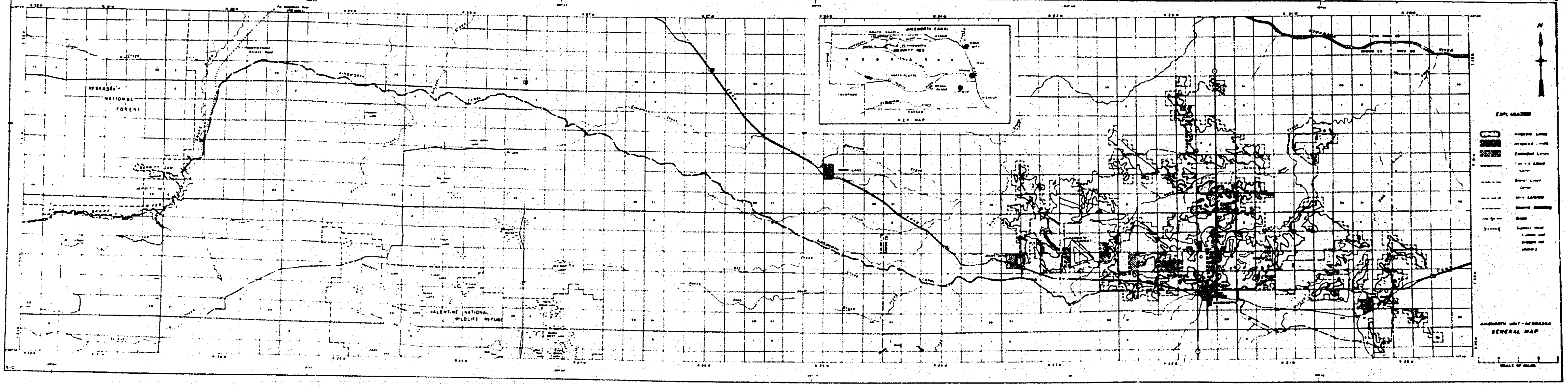
(3) 0.5-1.0 gallon per square yard RC-0

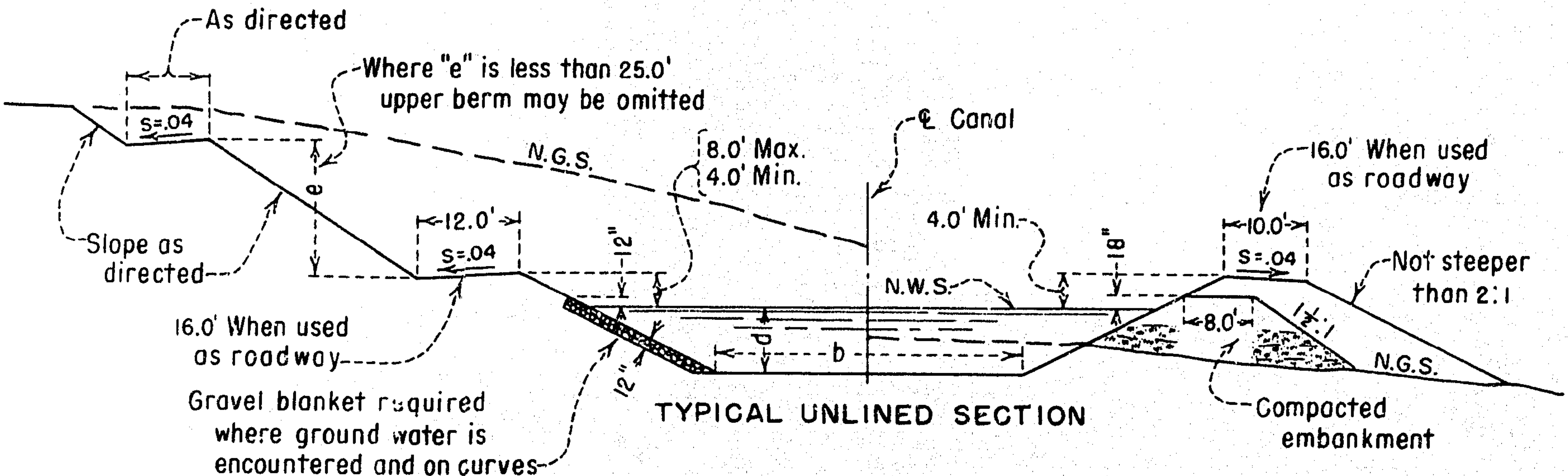
b.(1) HRM (mixing grade) emulsion diluted with water to provide at least 1.0 gallon of emulsion per square yard. The dilution should be determined in the field. Laboratory tests indicate that successive applications of emulsion must follow closely to prevent the emulsion breaking and the asphalt fraction filling the voids in the sand, preventing further penetration

(2) Final application of 0.5 gallon per square yard of 1 part HRM to 2 parts of water

Penetrated macadam cover, consisting of fine gravel penetrated with a rapid-setting emulsion, withstood high tractive forces and was unaffected by freezing and thawing action.

FIGURE 1
REPORT HYD 193





TYPICAL UNLINED SECTION

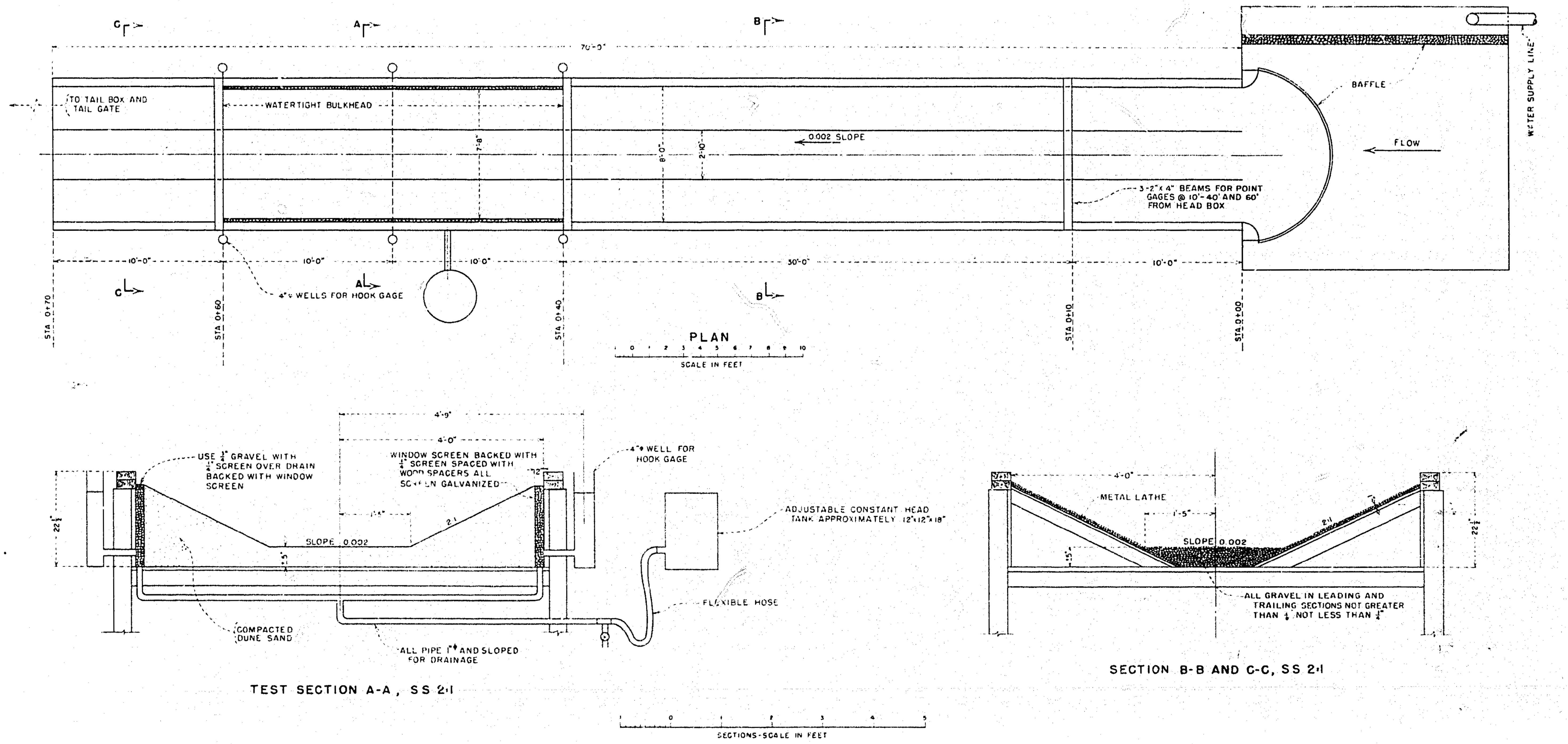
AINSWORTH CANAL
HYDRAULIC PROPERTIES
PRELIMINARY DESIGN

SECTION		SOIL	GROUND WATER	SIDE SLOPES	A	V	Q	b	d	r	n	t_f	s
	UNLINED	VOLCANIC ASH	NO	$2\frac{1}{2}$:1	480.0	1.83	876	40.0	8.0	5.78	.0225	.035	.00007
					504.0	1.84	928	43.0	8.0	5.85	.0225	.035	.00007
					528.0	1.86	982	46.0	8.0	5.93	.0225	.035	.00007
	UNLINED	DUNE SAND	NO	2:1	424.0	2.08	881	37.0	8.0	5.83	.0225	.045	.00009
					448.0	2.10	939	40.0	8.0	5.91	.0225	.045	.00009
					464.0	2.11	980	42.0	8.0	5.97	.0225	.045	.00009
	UNLINED	DUNE SAND	YES	$2\frac{1}{2}$:1	480.0	1.83	876	40.0	8.0	5.78	.0225	.035	.00007
					504.0	1.84	928	43.0	8.0	5.85	.0225	.035	.00007
					528.0	1.86	982	46.0	8.0	5.93	.0225	.035	.00007

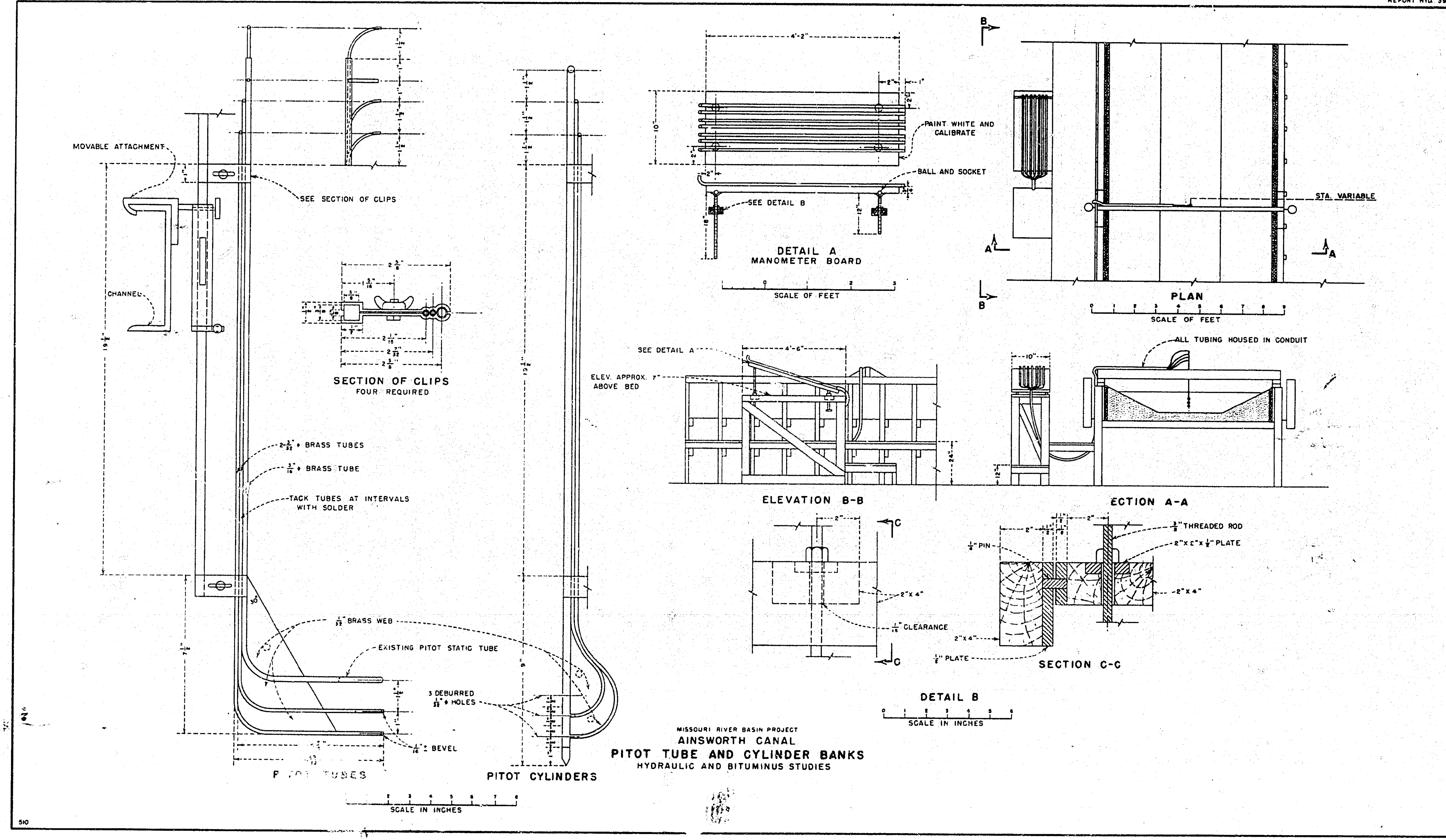
510

FIGURE 2
REPORT HYD. 393

FIGURE 3
REPORT HYD 393

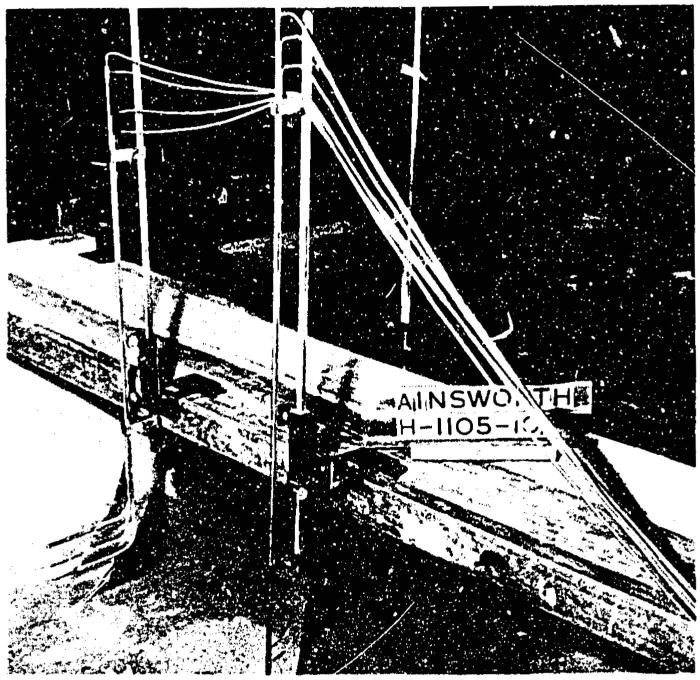


MISSOURI RIVER BASIN PROJECT
AINSWORTH CANAL
HYDRAULIC MODEL
HYDRAULIC AND BITUMINUS STUDIES

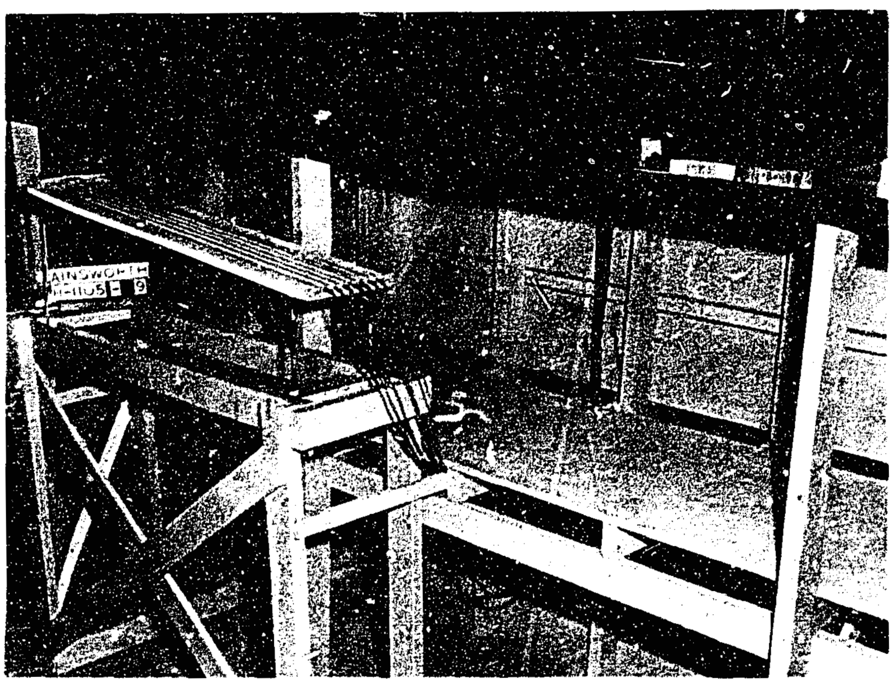


MISSOURI RIVER BASIN PROJECT
AINSWORTH CANAL
PITOT TUBE AND CYLINDER BANKS
HYDRAULIC AND BITUMINUS STUDIES

510

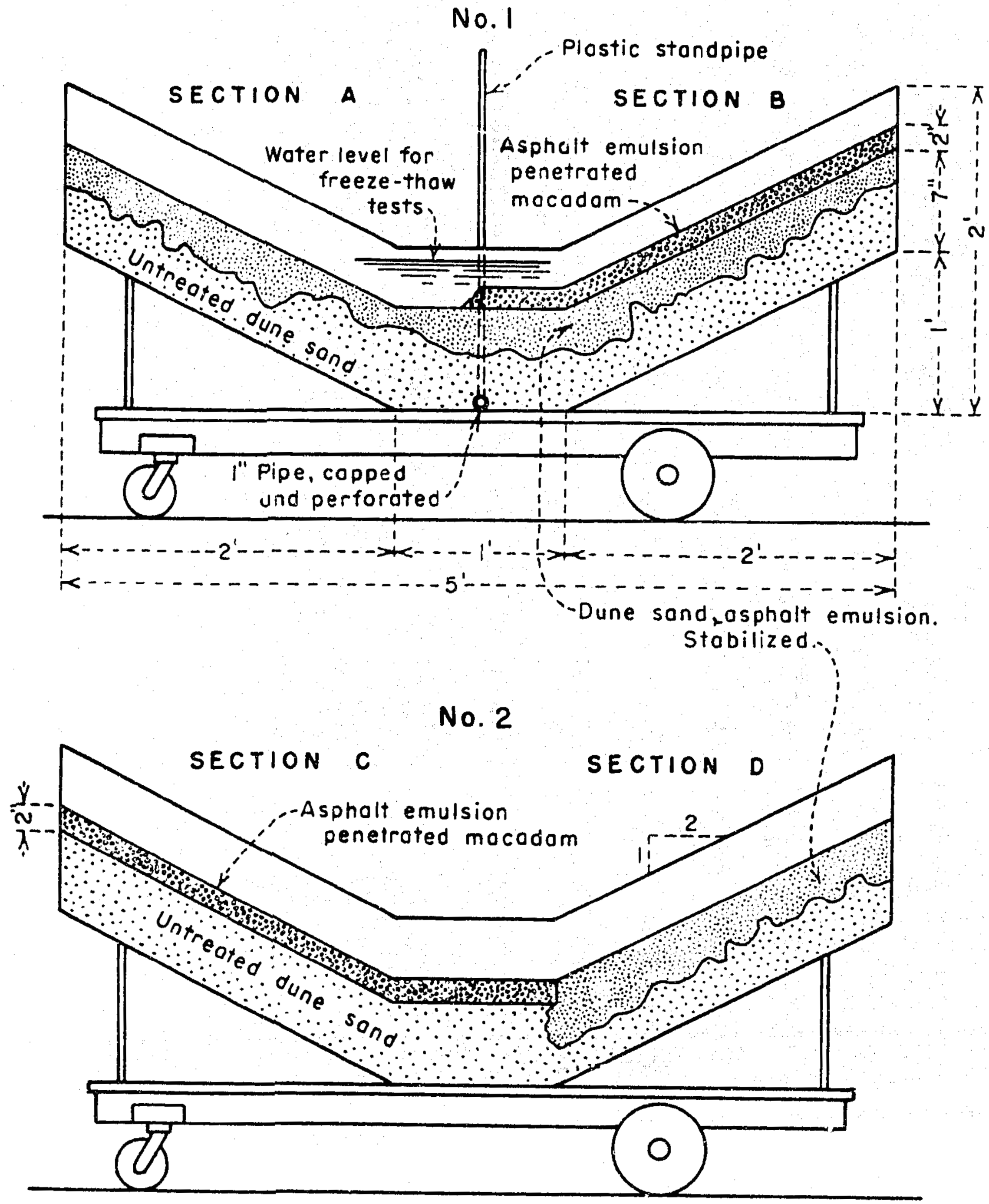


(a) Traversing pitot tube and pitot cylinder banks mounted on level channel iron



(b) Sloping manometer board-- connected with pitot banks

Missouri River Basin Project
AINSWORTH CANAL
PITOT BANKS AND MANOMETER BOARD
hydraulic and bituminous studies

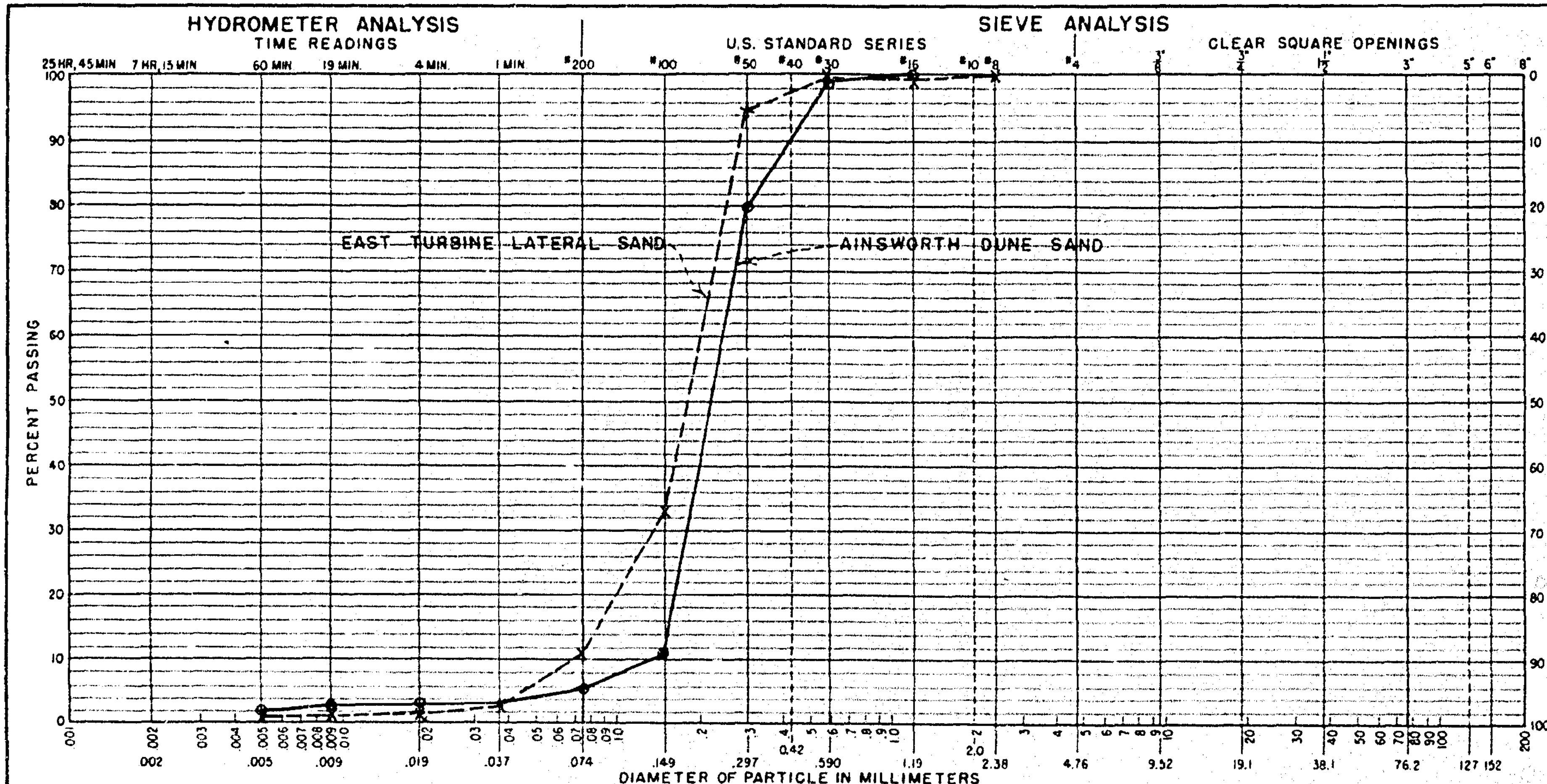


16 GA. WELDED-BLACK IRON
SHEET METAL

MISSOURI RIVER BASIN PROJECT
AINSWORTH CANAL
FREEZE-THAW TEST TRAYS
HYDRAULIC AND BITUMINOUS STUDIES

DRAWN BY ____________ CHECKED BY ____________ DATE ____________

FIGURE 7
REPORT HYD. 393



CLAY (PLASTIC) TO SILT (NON-PLASTIC)	SAND			GRAVEL		COBBLES
	FINE	MEDIUM	COARSE	FINE	COARSE	

NOTES:

AINSWORTH DUNE SAND—NEAR HACKBERRY LAKE NEBRASKA
TYPICAL OF MATERIAL ON PROPOSED ROUTE OF AINSWORTH CANAL

EAST TURBINE LATERAL SAND-SUBGRADE, 1.48, ROZA DIVISION
YAKIMA PROJECT

GRADATION TEST
MISSOURI RIVER BASIN PROJECT
AINSWORTH CANAL
SAND GRADATIONS
HYDRAULIC AND BITUMINOUS STUDIES

510

LABORATORY SAMPLE No. ____________ FIELD DESIGNATION ____________ EXCAVATION No. ____________ DEPTH ____________ FT.

GPO 82 8C0224

FIGURE NO.

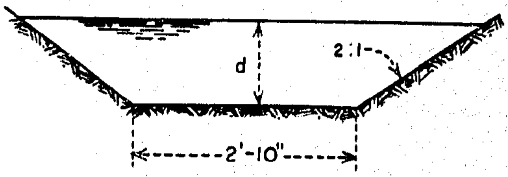
(a) Dyed sand strips before test

(b) Movement of dyed sand has started. Average tractive force is 0.0041 lbs per square foot. Note that near the bottom of the side slopes maximum movement has occurred.

Missouri River Basin Project
AINSWORTH CANAL
DYED SAND OBSERVATIONS

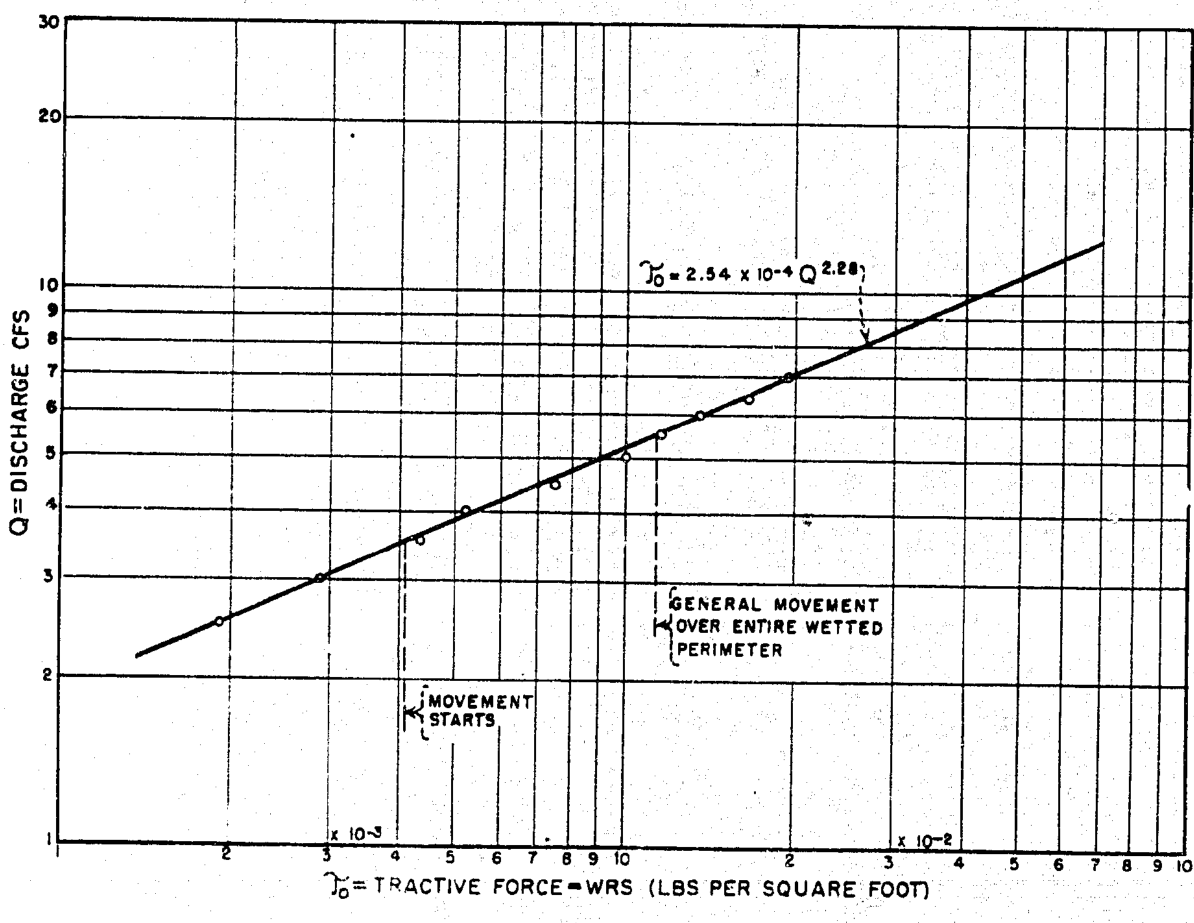
hydraulic and bituminous studies

Figure 8



CHANNEL SHAPE

AVERAGE DEPTH = 1.00 FT.
W = 62.4 LBS. PER CUBIC FOOT
R = HYDRAULIC RADIUS
S = HYDRAULIC GRAIDIENT



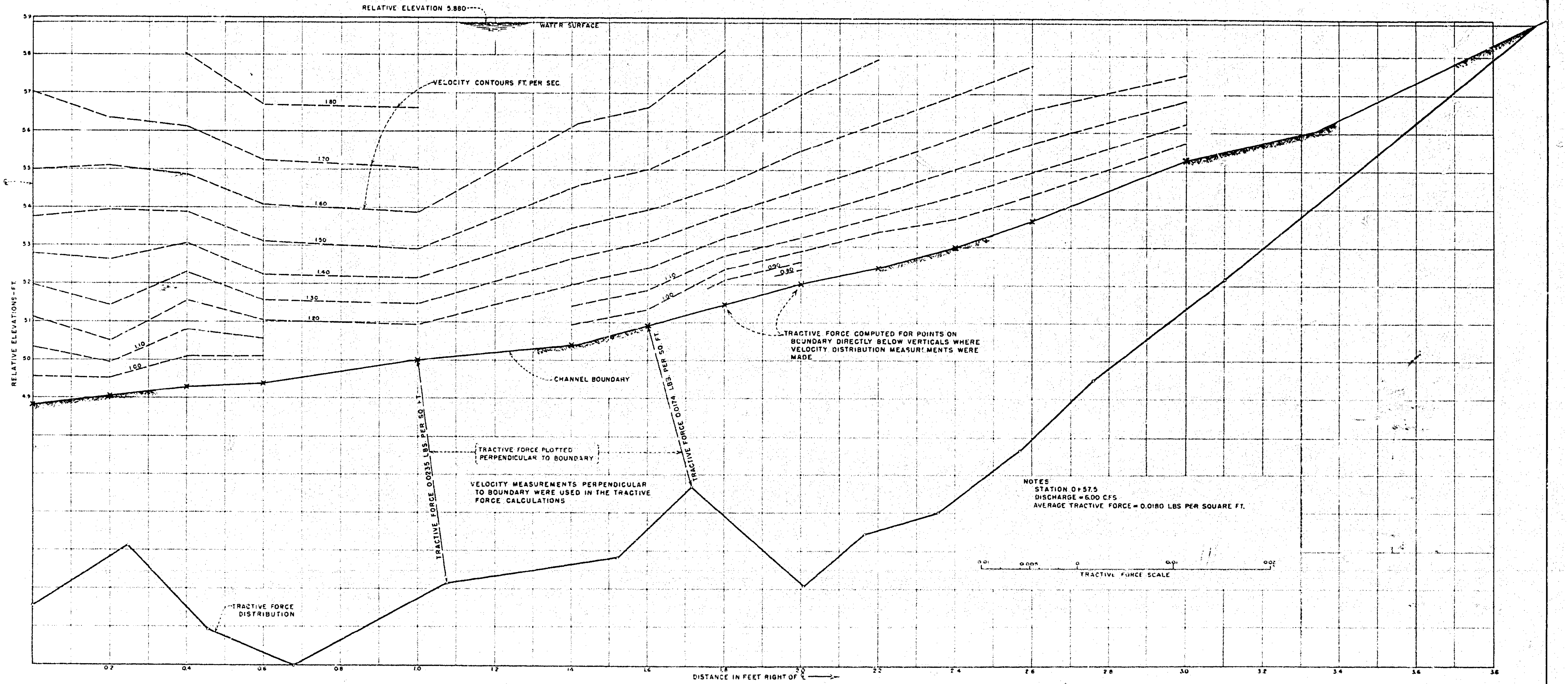
MISSOURI RIVER BASIN PROJECT

AINSWORTH CANAL

AVERAGE TRACTIVE FORCE vs DISCHARGE

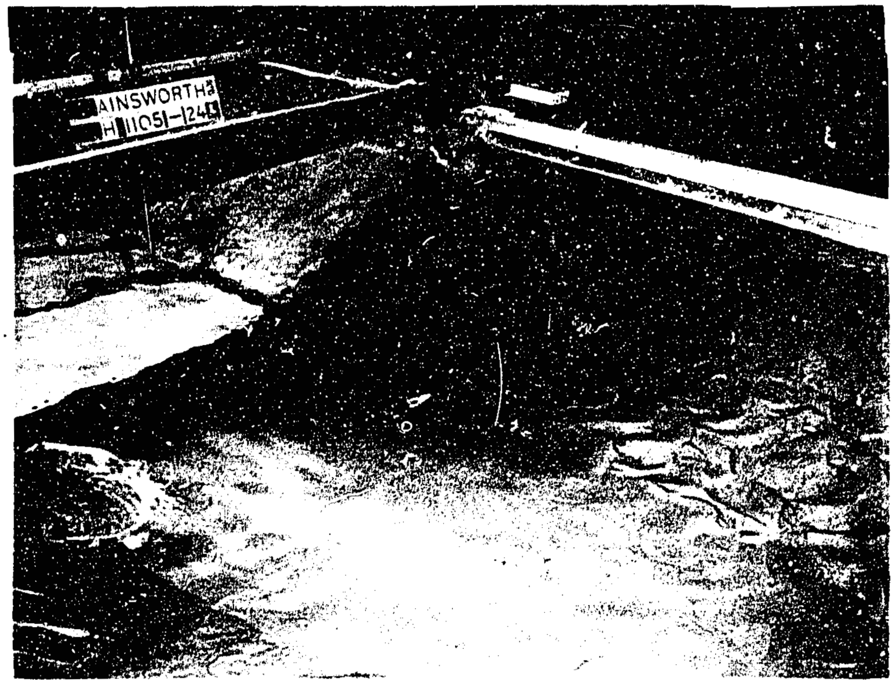
HYDRAULIC AND BITUMINOUS STUDIES

FIGURE 10
REPORT HYD 393

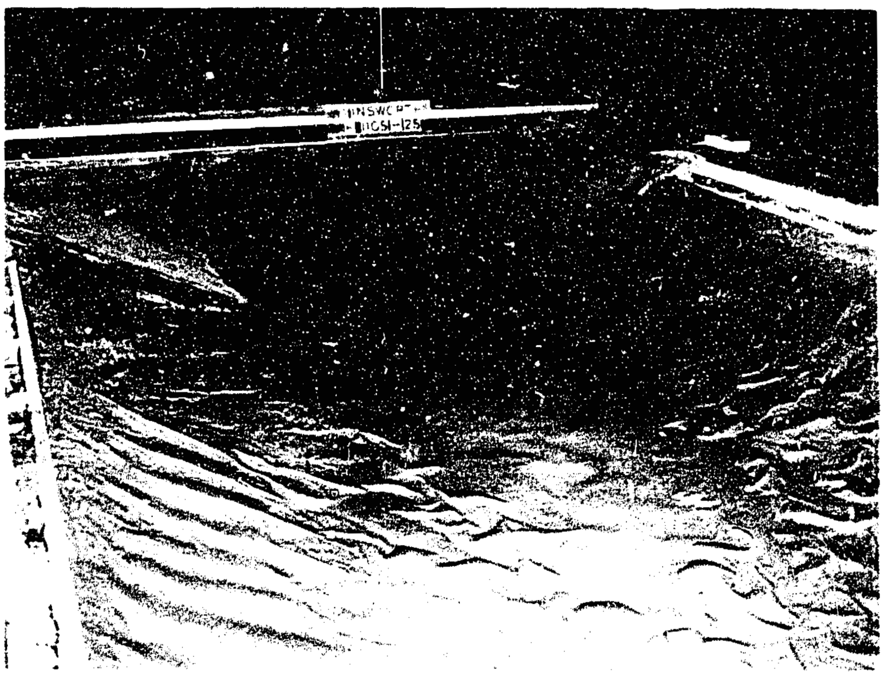


MISSOURI RIVER BASIN PROJECT
AINSWORTH CANAL
TRACTIVE FORCE DISTRIBUTION
HYDRAULIC AND BITUMINUS STUDIES

Figure 11

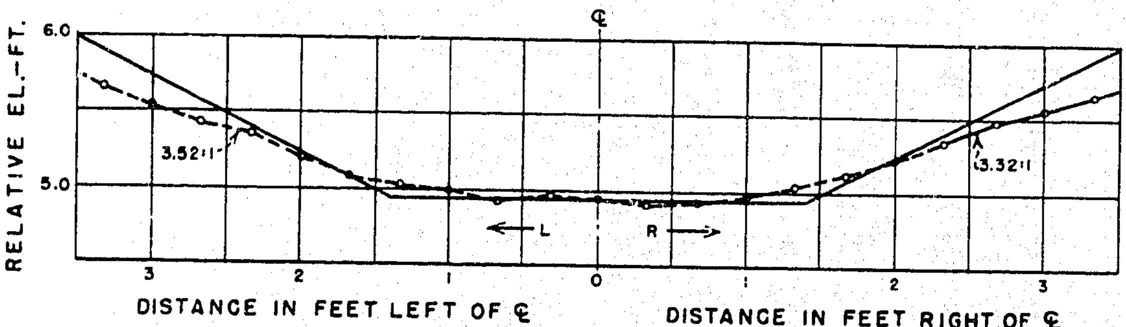


(a) Forty five minutes after ground water was introduced

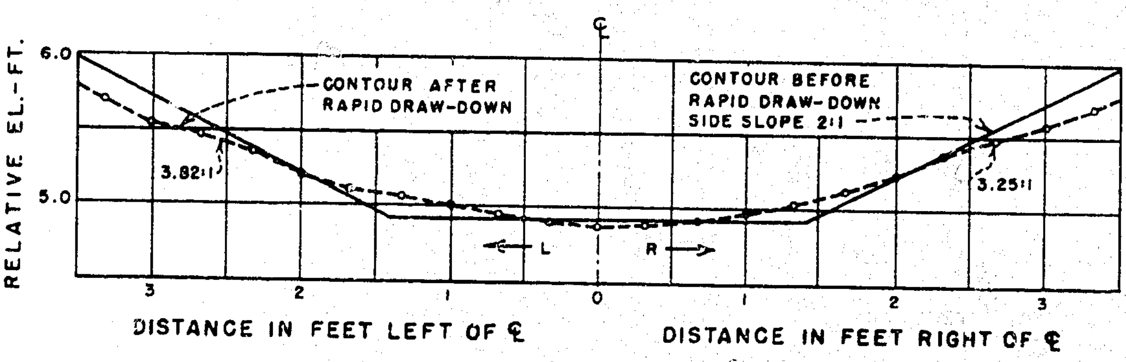


(b) Seven and one half hours after ground water was introduced

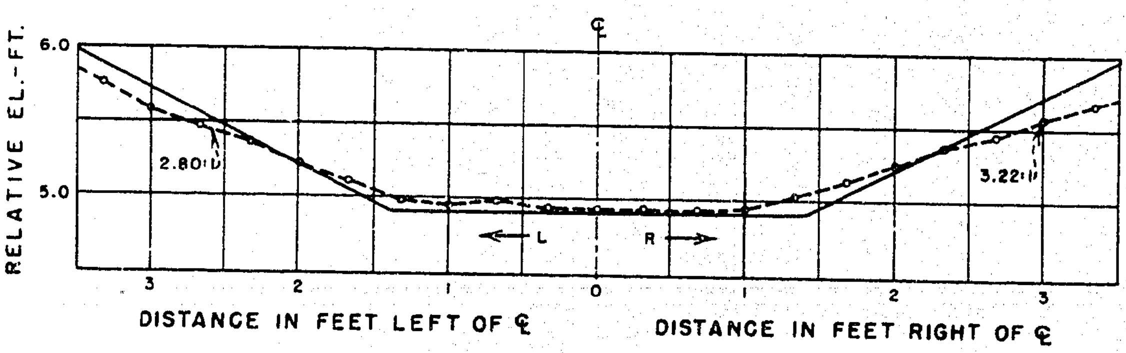
Missouri River Basin Project
AINSWORTH CANAL
SLOUGHING OF DUNE SAND CAUSED BY GROUND WATER
(THERE IS NO DISCHARGE IN THE MODEL)
hydraulic and bituminous studies



STATION 0+45



STATION 0+50

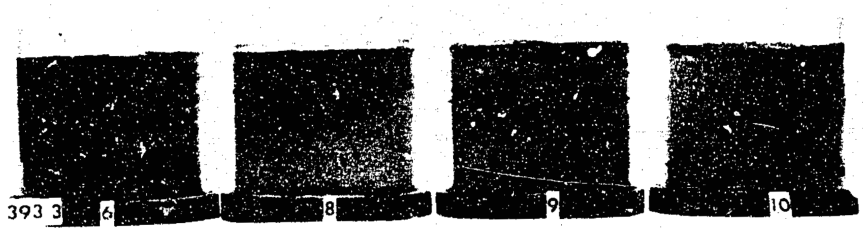


STATION 0+58

AVERAGE SIDE SLOPE AFTER RAPID DRAW-DOWN = APPROXIMATELY 3.33:1
FLOW INTO PAPER

MISSOURI RIVER BASIN PROJECT
AINSWORTH CANAL
SLOUGHING OF DUNE SAND
CAUSED BY RAPID DRAW-DOWN
HYDRAULIC AND BITUMINOUS STUDIES

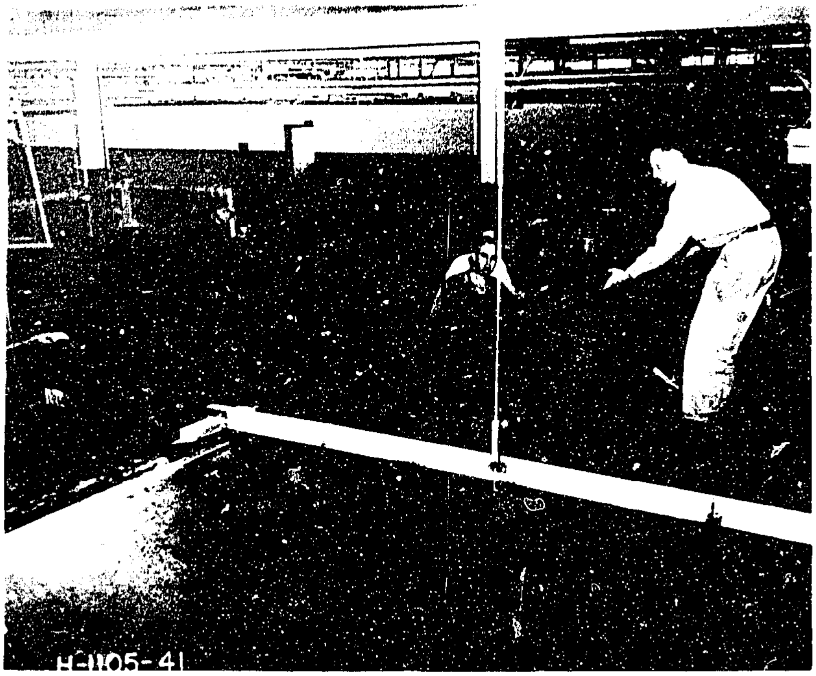
(a) Test cylinders 1 through 5



(b) Test cylinders 6, 8, 9, and 10

Missouri River Basin Project
AINSWORTH CANAL
CYLINDERS USED IN SURFACE-PENETRATION TESTS
hydraulic and bituminous studies

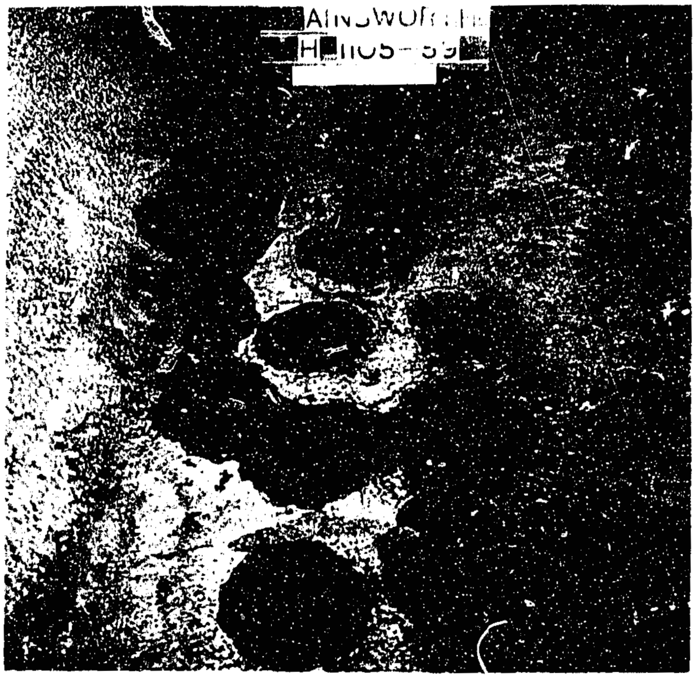
Figure 14



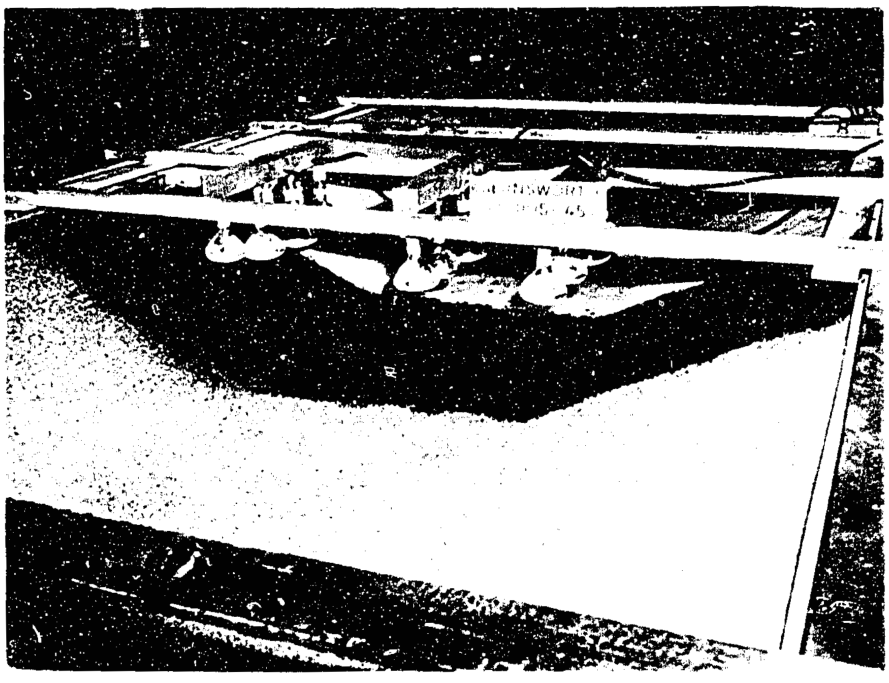
(a) Hand spraybar and Chausee, standard model T-200, asphalt distributor

(b) Tank-type Hudson sprayer, model 253

Missouri River Basin Project
AINSWORTH CANAL
APPLYING DILUTE ASPHALT EMULSIONS
hydraulic and bituminous studies

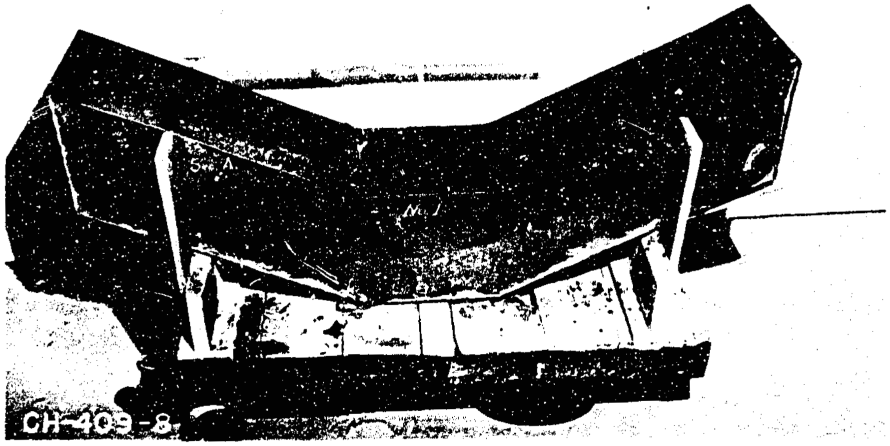


(a) Asphalt emulsion stabilized dune sand showing erosion in burned areas which were produced during curing

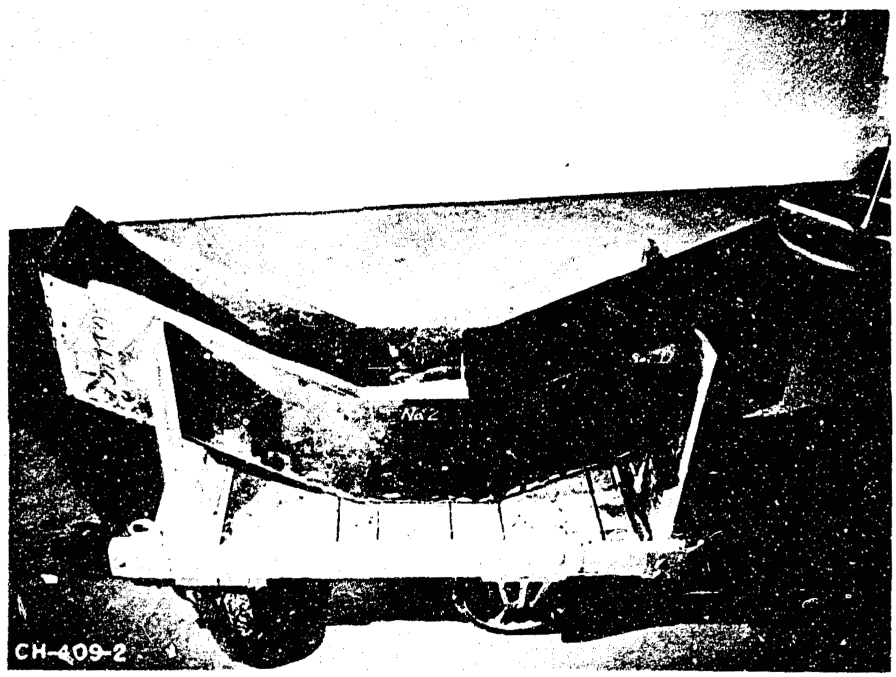


(b) Penetrated macadam cover consisting of asphalt emulsion and pea gravel. Note infra-red lamps used for curing

Missouri River Basin Project
AINSWORTH CANAL
ASPHALT EMULSION TEST SECTIONS
hydraulic and bituminous studies

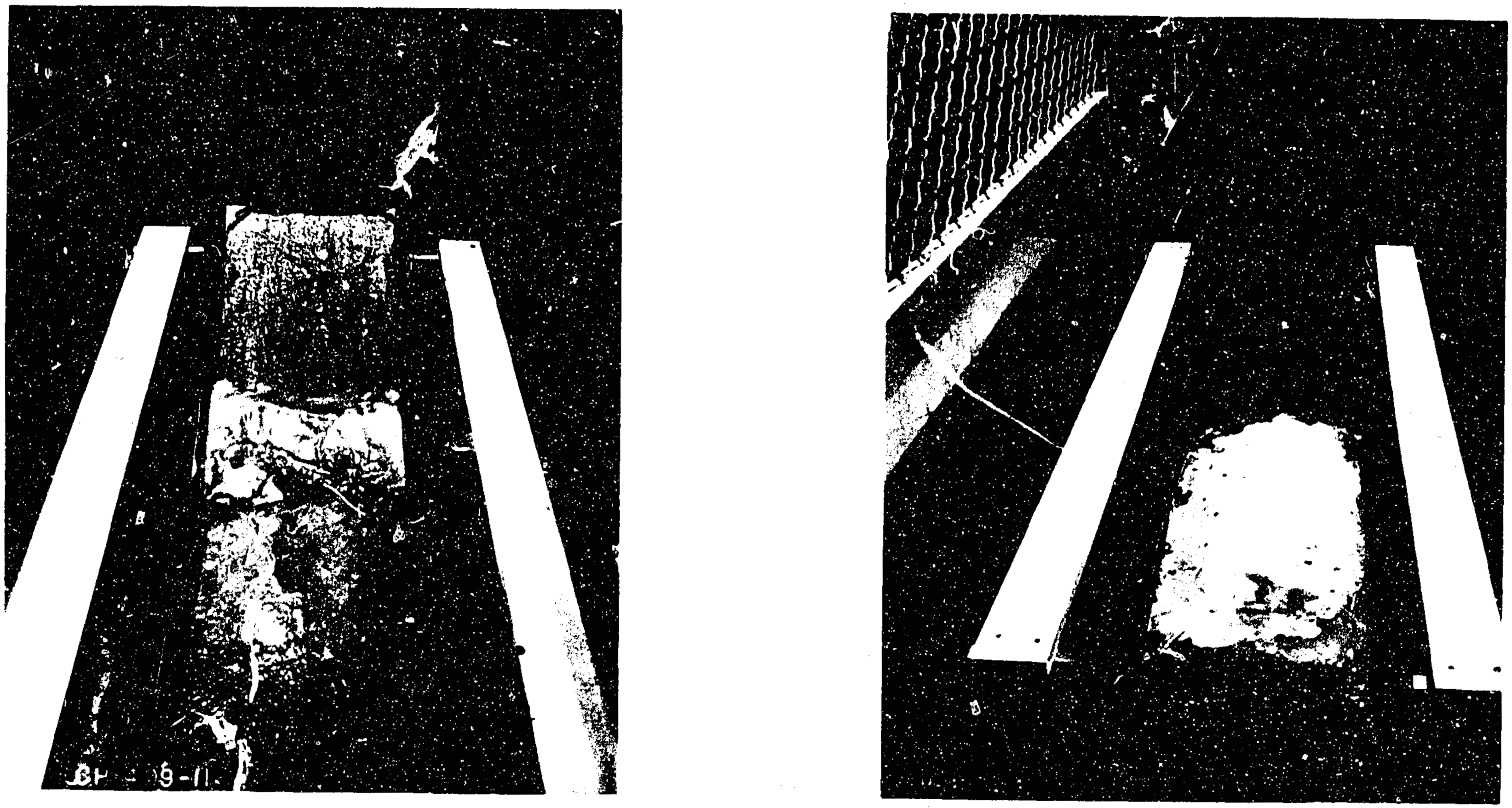


(a) Tray 1. Dune sand penetrated with diluted asphalt emulsion. Section B shows the 2-inch thick asphalt emulsion penetrated macadam cover.



(b) Tray 2. Section C- dune sand at field "in place" density. A 2-inch thick asphalt emulsion penetrated macadam cover was placed over section C. Section D- dune sand penetrated with diluted asphalt emulsion.

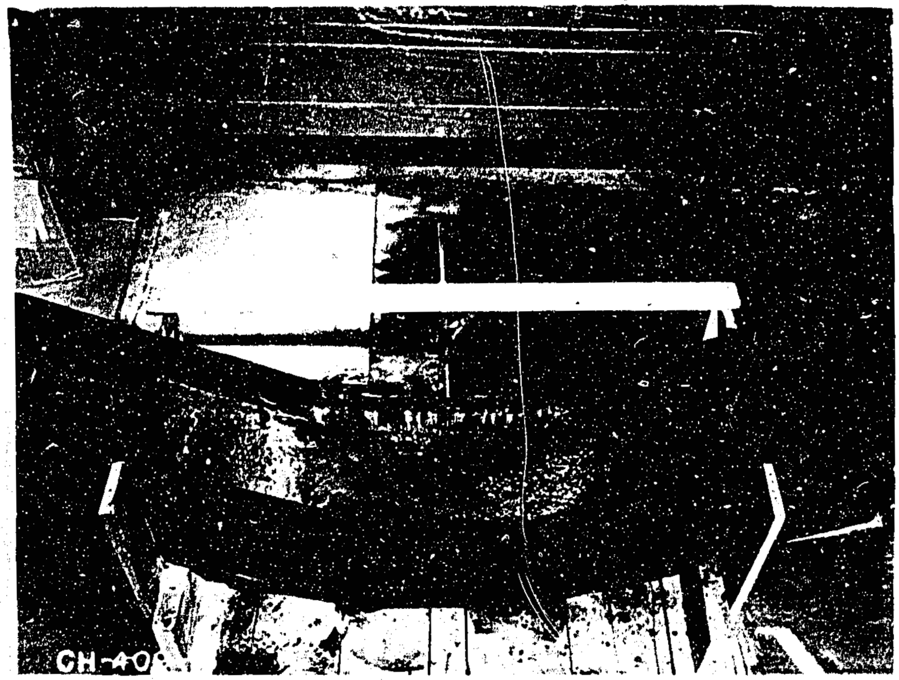
Missouri River Basin Project
AINSWORTH CANAL
FREEZE-THAW TRAYS PRIOR TO TEST
hydraulic and bituminous studies



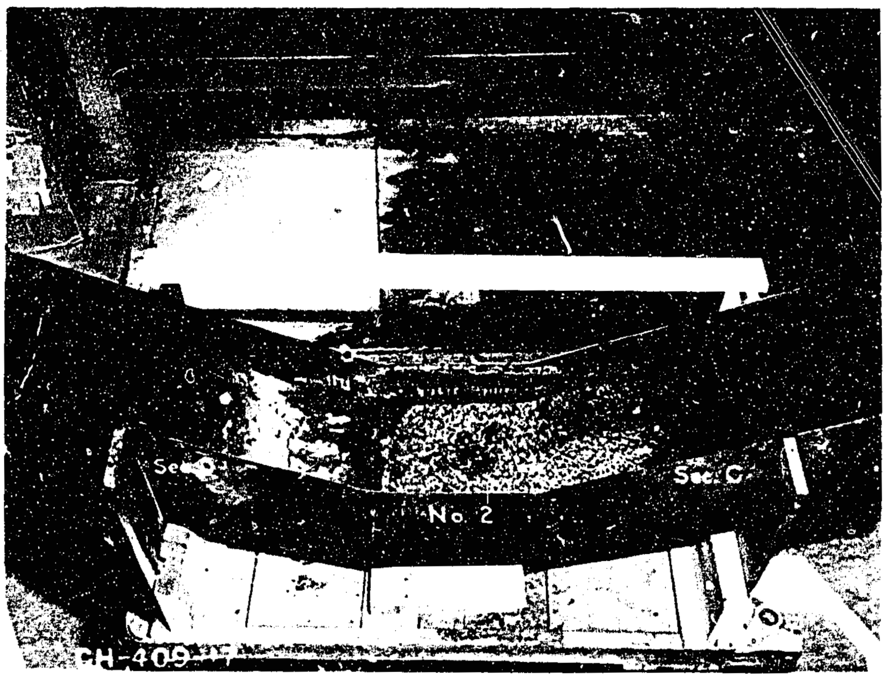
(a) Tray 1 (b) Tray 2

Missouri River Basin Project
AINSWORTH CANAL
FREEZE-THAW TRAYS AFTER REMOVAL FROM FREEZING ROOM
hydraulic and bituminous studies

Figure 17



(a) Tray 1. Note: Section A, firm but cracked above waterline, uncoated sand and some sloughing below waterline. Section B was uneffected. Discoloration on gravel is due to rust deposit.



(b) Tray 2. Section C (at right) unaffected. Section D (at left) same as Section A.

Missouri River Basin Project
AINSWORTH CANAL
TRAYS AT COMPLETION OF FREEZE-THAW TESTS
hydraulic and bituminous studies